J. Johann Esq
Compl of C. A. S.

REPORT

OF

ENGINEERS OF THE U. S. NAVY

UPON

Experiments with Saturated and Superheated Steam

MADE AT THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,

MARCH, 1877.

BOSTON:
FRANKLIN PRESS: RAND, AVERY, & COMPANY.
1877.

POUNDS OF COAL CONSUMED

PER NET HORSE-POWER, PER HOUR,

AS SHOWN BY EXPERIMENTS UPON THE UNDERMENTIONED STEAMERS.

NAME OF STEAMER	KIND OF ENGINE	KIND OF STEAM USED	Boiler Pressure above Atmosphere. lbs. pr. sq. in.	ACTUAL CUT-OFF	Pounds of Coal Consumed per Net Horse Power per hour
Michigan	Non-Compound	Saturated	21	.29	4.5
Mackinaw	"	"	35	·43	3·49
Eutaw	"	"	27	·54	3·84
Dexter	"	"	67	.29	3·4
Dallas	"	"	32	·31	3·8
Bache	Compound Jacketed	"	80	.20	2.66
Rush	"	"	69	.16	2.71
Georgeanna	Non-Compound	Superheated	33	·31	2.58
Adelaide	"	"	34	·39	2 45
Mackinaw	"	"	39	.29	2.48
Eutaw	"	"	28	·54	2.99

DEAR SIR:

In handing you a copy of the report of Naval Engineers, upon experiments at the Massachusetts Institute of Technology, I would draw your attention to what had already been proved by previous experiments.

This will be shown by the accompanying table, from which it appears that the Georgeanna, Adelaide, Mackinaw and Eutaw, working with superheated steam at moderate pressures and without jackets, surpassed the performances of jacketed Compound Engines working with much higher pressures and much greater expansion.

Had the pressures in the first-named steamers been 80 or 90 lbs., the power would have cost less by about 20 %, even without shortening the cut-off.

This shows that a very satisfactory result may be reached in single engines, although by compounding and superheating for both cylinders a still better effect may be produced

The experiments at the Institute, owing to leakage and the greater radiation from a small engine, do not bring out so fully the advantages of superheated over saturated steam, but they demonstrate all those peculiarities in the action of superheated steam which they were designed to show, and the necessity for adopting those precautions which I have named in my patents, and in my pamphlet on Cylinder Condensation.

Faithfully yours,

GEORGE BASIL DIXWELL.

BOSTON, May 9, 1877.
No. 23 BEACON STREET.

Jacob Johann

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BOSTON, MASS., March 24, 1877.

SIR: In obedience to your orders of the 6th inst., we have witnessed a number of experiments made at the Massachusetts Institute of Technology by Mr. George B. Dixwell, and beg leave to report as follows: —

In the apparatus employed, steam was taken from the horizontal tubular boilers which supply steam for heating the buildings of the Institute of Technology, and for other purposes.

The engine is of the well known *Corliss* type, of 8 inches diameter and 24 inches stroke of piston. The cut-off is varied by an Allen governor. The entire clearance is $\frac{41}{1000}$ of the space displacement of the piston.

The power developed by the engine is absorbed by a friction brake, applied to the fly-wheel.

The exhaust-steam from the engine passes to the *calorimeter*, which comprises the following details:—

1. A tank built of planks two inches thick, of about 120 cubic feet capacity, containing a system of tubular metallic condensing surfaces, the interior of the latter being in communication with the exhaust-pipe of the engine and with the receiving-tanks hereinafter described. The body of the tank may be filled with water from the city aqueduct, by which heat in the steam discharged from the cylinder into the system of condensing-tubes will be absorbed. To relieve the walls of the tank from pressure resulting from the expansion of the water in heating, a small vessel of ten feet cubical capacity, two feet high, of wood, is placed above the large

tank described above, communicating with the latter by a pipe of two inches diameter. Through this pipe the expanding water may rise to the upper vessel described, which is called the *expansion tank.* The escape of vapor is prevented by a floating cover in the expansion tank, joined to the walls by a flexible diaphragm. The large tank, the expansion tank, and their contents and appendages, stand upon the platform of a Fairbanks scales. Freedom of movement, within sufficiently wide limits, is maintained by fitting the pipe connections of the tank with rubber tubing; and the weighing is accurate within two pounds; the whole weight, tanks, appurtenances, and water, being 8,100 pounds.

The tank is fitted with thermometers for ascertaining the temperature of the hydrant water entering, and of the water contained. To insure equality of the latter quantity in all parts of the tank chamber, a device for circulating the water is provided, to be worked by hand.

The fall of pressure in the condenser-tubes, below that of the atmosphere, is averted by the automatic action of a reverse, or vacuum, valve.

2. The pipe leading from the lower end of the condensing-tubes, through which the water resulting from condensation passes out of the large tank, enters a small tank, which, like the others, is made of two-inch plank. This tank stands upon the platform of a second Fairbanks scales, and is fitted with a thermometer for ascertaining the temperature of its contents. This tank may be emptied through a pipe leading to the sewer. The pipe connections are, like those of the large tank, flexible, so as to admit of weighing.

The superheating apparatus consists of a cylindrical boiler, of iron, seven feet long and three feet in diameter, fitted with fifty iron tubes two inches in diameter and five feet long. The latter are fire-tubes, vertical, and six inches of the lower end covered with water. The superheater is set in brickwork, in which an annular space allows the products of combustion to pass downward, around a part of the shell. The

furnace is of brick-work, so far removed from the heating surfaces as to prevent direct radiation to them from the fuel. In this vessel the steam from the boiler may be superheated above 600° F.

The superheated steam is delivered to the engine through a $2\frac{1}{2}$-inch pipe. At the receiving end of this pipe, a pipe of $1\frac{1}{2}$ inches diameter delivers saturated steam, the admission being regulated so as to govern the temperature of the steam passing through the pipe, which nevertheless remains superheated to a degree measured by a Bulkley pyrometer, placed five or six feet beyond.

A mercurial thermometer is placed close to the steam-chest of the engine, in the steam-pipe, and another Bulkley pyrometer in the clearance space of the cylinder. A mercurial thermometer is also placed at the point last mentioned. During a part of the experiments, a mercurial high-grade thermometer was placed nearly midway of the length of the steam-pipe.

Besides the pipes described, others, connecting the engine directly with the generator, are fitted. These are cut off from the former at will, by gate-valves made perfectly tight.

An indicator was fitted to each end of the cylinder.

The experiments were made in pairs, as follows: —

1st, Saturated steam, $\frac{1}{4}$ cut-off; followed by one at the same cut-off with superheating.

2d, Saturated steam, $\frac{7}{10}$ cut-off; followed by one at the same cut-off with superheating

3d, Saturated steam, $\frac{1}{2}$ cut-off; followed by one at the same cut-off with superheating.

Diagrams from each end of the cylinder were taken, and readings from the pressure gauge and thermometers, and of the weighing scales, were registered every five minutes. The large tank was heated, before the beginning of each experiment, to the temperature at which it was desired to close the experiment; then emptied, and weighed empty; then filled with water from the city aqueduct, at the natural tempera-

ture, the temperature observed, and the full tank weighed. Throughout each experiment the water in the tank was kept in motion, that the circulation might prevent differences in temperature within it. The temperature and weight of the tank water at the end of the experiment was registered, after clearing the condensing-tubes of water. The water delivered into the small receiving-tank was also weighed, and its temperature ascertained every five minutes. From these quantities the total heat of the steam leaving the cylinder is computed.

It was sought to maintain in the cylinder, during each experiment with superheated steam, a temperature of 310° F., and an initial pressure of 50 pounds by the gauge.

It will be seen from the Table hereto appended, which contains the averages of all the observations recorded, that this was very nearly accomplished.

It will also be seen, that, to maintain the above temperature within the cylinder, a varied degree of superheating was necessary, accordingly as the cut-off was varied.

The relations of the cut-offs, the pressures, the temperatures, and the losses, will appear from inspection of the Table and the diagrams appended, the latter being selected from among those nearest the mean of the whole. The dotted lines on the latter are true hyperbolic curves plotted for comparison.

After the experiments were completed, the correctness of the instruments used was verified by the very accurate methods of the Institute of Technology. It was then ascertained that some leakage of piston and valves had existed. This leakage affects the *cost* of the power, but not the correctness of the deductions from the data obtained, in their bearings upon the object of the experiments.

The experiments of Mr. Dixwell may be treated as supplementary to those made by the Navy Department, and recorded in the second volume of "Isherwood's Researches in Steam Engineering," since the questions they are intended to answer grow out of an investigation of those records.

Mr. Dixwell says, —

"The object is to demonstrate two facts which had previously been inferred from an examination of the experiments made by Chief Engineer Isherwood with superheated steam on board the steamers 'Georgeanna' and 'Adelaide,' as described in the second volume of 'Experimental Researches in Steam Engineering.' These were, —

1. That, with steam working expansively, the temperature of the cylinder is much below that of the superheater.

2. That, in order to maintain a given temperature in the cylinder, the steam must be superheated less for a small measure of expansion, and more for a large measure."

The following points are noticeable features of the experiments, and of the action of the apparatus: —

1. Throughout all the experiments with saturated steam, considerable variations in the temperature of the cylinder were indicated by the thermometer and the pyrometer during every stroke of the piston. The amplitude of the vibrations of the pyrometer extended over nineteen degree-marks of the dial. But throughout the whole of every stroke of the piston, during the experiments with superheated steam, these instruments constantly indicated a fixed degree of temperature, showing no vibrations whatever.

At the close of the half-stroke and the seven-tenths stroke cut-off experiments with superheated steam, the same instruments showing no vibrations, the cut-off was shortened without change in the superheating: vibrations of considerable amplitude were presently observed in them.

2. The remarkable fall of temperature of the steam in passing from the superheater to the steam-chest, before entering the latter, being, for $\frac{1}{4}$ cut-off, 97°; for $\frac{1}{2}$ cut-off, 49°; for $\frac{7}{10}$, 19°.

3. During experiments with superheated steam, the opening of the indicators for preliminary heating was attended by a sudden fall of 15° F. within the cylinder, the temperature gradually rising again as the metal of the indicators became heated.

After using superheated steam, five minutes were required for a fall of 15°, the steam being shut off.

It appears to the Board that the record sustains the views of Mr. Dixwell so far as the scope of the experiments will enable them to judge.

We are, sir,

Very respectfully,

Your obedient servants,

CHAS. H. LORING,

Chief Engineer U.S.N.

CHAS H. BAKER,

Chief Engineer U.S.N.

EDWARD FARMER,

Chief Engineer U.S.N.

Engineer-in-Chief,

WM. H. SHOCK, U. S. Navy,

Chief of the Bureau of Steam Engineering,

Navy Department, Washington, D.C.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Number for Reference.	Date of Experiment.	Kind of Steam used.	Apparent Cut-off.	Actual Cut-off.	Temperature of Steam in Steam-pipe.			Temperature in Cylinder.		Temperature in Exhaust-pipe.	
					By Pyrometer near Superheater.	By Middle Thermometer.	By Thermometer near Throttle.	By Pyrometer.	By Thermometer.	By Pyrometer.	By Thermometer.
								Vibrations.	Vibrations.		
1	Mar. 15, '77,	Saturated.	.217	**.247**	....	....	302	278 to 297	263 to 267	210	213
2	" 17, "	"	.443	**.465**	....	....	303	279 to 296	264 to 268	210	213
3	" 16, "	"	.689	**.701**	....	....	303	282 to 300	268 to 273	213	215
4	" 15, "	Superheated.	.218	**.248**	**575**	....	478	**313**	**300**	217	217
5	" 17, "	"	.439	**.461**	**490**	486	441	**316**	**306**	210	213.5
6	" 16, "	"	.672	**.685**	**425**	....	406	**315**	**305**	212	213

[NOTE. — The above temperatures are the uncorrected indications of the instruments, which, tested under a pressure of 50 lbs. in saturated steam, indicated as follows: Pyrom. in St. Pipe, 296; Mid. Th. 300; Thermom. near Throttle, 303: Cyl. Pyrom. 299; Cyl. Th. 294; Exhaust Pyrom. 296; Th. 296. — *G. B. D.*]

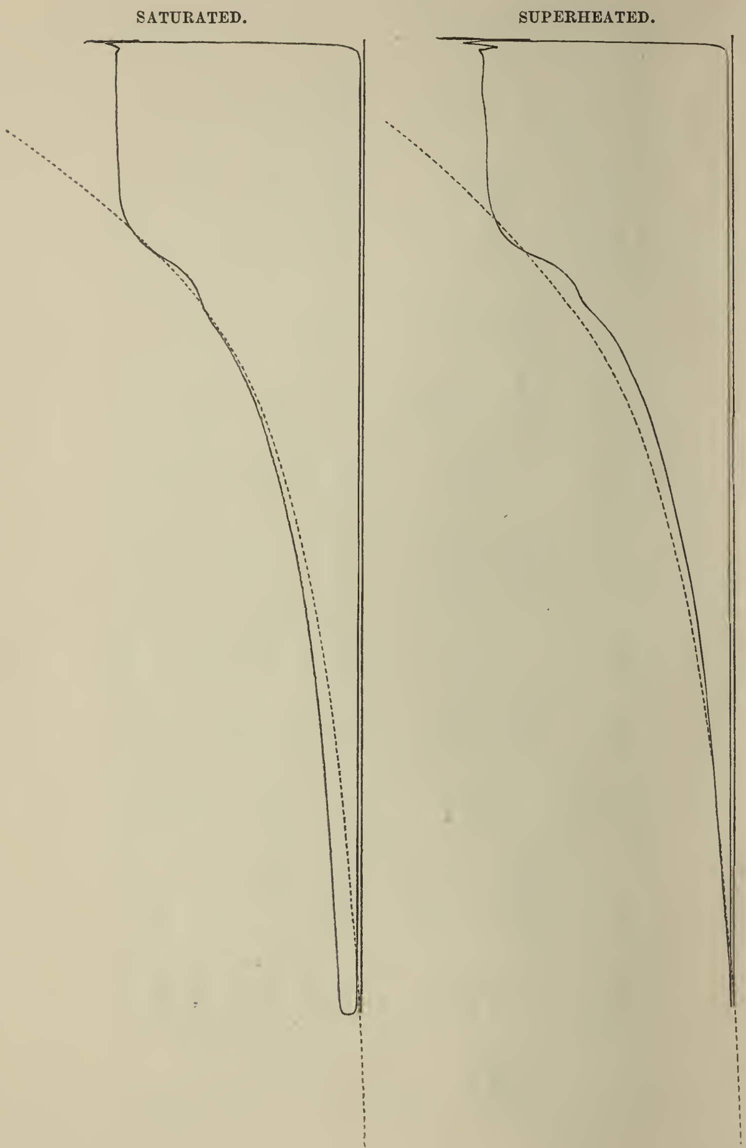
	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.
						Pressures in Cylinder above Zero shown by Indicator.							
Number for Reference.	Duration of Experiment in Minutes.	Whole Number of Revolutions during Experiment.	Revolutions per Minute.	Total weight of Water consumed by Engine during Experiment.	Boiler Pressure above Atmosphere by Gauge.	Initial Pressure.	Pressure at Cut-off.	Pressure at Release.	Pressure at Cushion.	Fraction of stroke uncompleted at Exhaust Closing.	Mean Total Pressure.	Mean Back Pressure.	Mean Gross Effective Pressure.
				lbs.									
1	127	7806	61.46	780.	50.4	65.	56.9	18.7	15.7	.01	36.06	15.35	20.71
2	83	5014	60.41	740.75	50.2	66.2	59.7	29.5	16.	.01	50.64	15.65	34.99
3	63	3656	58.03	746.25	50.3	66.2	61.3	44.5	16.5	.01	60.77	15.8	44.97
4	180.3	11006	61.04	722.	50.4	65.9	57.4	15.1	15.5	.01	33.77	15.15	18.62
5	108	6646	61.44	705.75	50.	66.6	58.8	26.	16.	.01	48.85	15.35	33.5
6	75	4462	59.49	700.	50.2	66.9	61.1	39.7	15.9	.01	59.16	15.45	43.71

	25.	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.
Number for Reference.	Weight of Water used per Stroke.	Weight of Steam remaining in Cylinder per Stroke at Exhaust Closing.	Sum of Column 25 and Column 26.	Weight of Steam alone at Cut-off, supposing Saturation.	Loss at Cut-off per Stroke.	Weight of Steam alone at End of Stroke, supposing Saturation.	Loss at End of Stroke per Stroke.	Percentage of Loss at Cut-off to Whole Steam used.	Percentage of Loss at End of Stroke to Whole Steam used.	Total Horse Power.	Gross Effective Horse Power.	Water per Total Horse Power per Hour.	Water per Gross Effective Horse Power per Hour.	Total Heat of Exhaust Steam shown by Calorimeter in Thermal Units above zero.
1	.04996	.00139	.05135	.02453	.02682	.03473	.01662	52.2	32.4	13.32	7.65	**27.66**	48.2	1046.
2	.07387	.00142	.07529	.04823	.02706	.05321	.02208	35.9	29.3	18.38	12.7	**29.14**	42.2	1084.5
3	.10206	.00146	.10352	.07465	.02887	.07877	.02475	27.9	23.9	21.19	15.68	**33.54**	45.3	1101.4
4	.03280	.00138	.03418	.02481	.00937	.02793	.00625	27.4	18.3	12.39	6.83	**19.39**	35.2	1138.6
5	.05309	.00142	.05451	.04709	.00742	.04712	.00739	13.6	13.6	18.03	12.37	**21.75**	31.7	1159.4
6	.07844	.00141	.07985	.07276	.00709	.07068	.00917	8.9	11.5	21.15	15.63	**26.48**	35.8	1170.8

MEAN DIAGRAMS. — Experiments of March 15, 1877.

Scale of Springs, 40 *lbs. to the inch.*

Water per Total Horse-Power per hour, 27.66 lbs. with Saturated Steam, 19.39 lbs. with Superheated Steam.



MEAN DIAGRAMS. — Experiments of March 17, 1877.

Scale f Springs, 40 *lbs. to the inch.*

Water per Total Horse-Power per hour, 29.14 lbs. with Saturated Steam, 21.75 lbs. with Superheated Steam.

MEAN DIAGRAMS.—EXPERIMENTS OF MARCH 16, 1877.

Scale of Springs, 40 *lbs. to the inch.*

Water per Total Horse-Power per hour, 33.54 lbs. with Saturated Steam, 26.48 lbs. with Superheated Steam.

SATURATED. SUPERHEATED.